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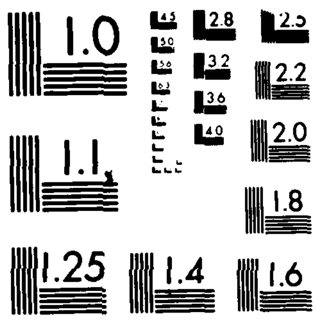

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CONTRACTOR REPORT ARLCD-CR-83048

EVALUATION AND DEMONSTRATION OF THE VIABILITY OF SALT BATH SOLUTION HEAT TREATMENT FOR DEPLETED URANIUM PENETRATORS

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MARCH 1984

U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER

LARGE CALIBER WEAPON SYSTEMS LABORATORY

DOVER, NEW JERSEY

AEROJET

HEAVY METALS DIVISION

AEROJET ORDNANCE COMPANY

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17 May 1984

Department of the Army
U. S. Army Armament Munitions
and Chemical Command (AMCCOM)
Picatinny Arsenal
Dover, NJ 07801

Attention: DRSMC-LCU-M, Mr. Doug Vanderkooi

Subject: Contract DAAK10-83-C-0005, Final Report; Publication of

Reference: (a) Telecon of C. Alesandro/AMCCOM and J. Hughes/Aerojet on 7 May 1984

Gentlemen:

As requested in referenced (a), Aerojet Ordnance Company, HMD, has changed the quantities from 14,000 and 5,500 to 10,000 and 4,000 M833 and XM829 respectively. To verify this change, please review page 26 of the attached report.

Distribution of the document is made in accordance with the list shown on pages 30 and 31. The subject contract has been closed out and is considered complete with the issuance of this document.

Should additional information be required, please contact me at Aerojet Ordnance Company, Jonesborough, TN; telephone (615) 753-4688.

Sincerely,

AEROJET ORDNANCE COMPANY

James F. Hughes

James F. Hughes
Contract Manager

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18. SUPPLEMENTARY NOTES

This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Depleted uranium
Salt bath solutionizing
Heat treatment
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An MM&T program to evaluate and demonstrate the viability of a salt bath solutionizing heat treatment for large caliber DU penetrators (0.75% by weight titanium) was conducted. One hundred M774 core blanks were evaluated to develop and verify the various process stages (e.g., outgassing salt residence times, etc) of salt heat treatment. A viable salt bath heat treatment process was

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20. ABSTRACT (contd)

developed through this program. A pilot lot of 40 finished machined M774 penetrators was fabricated under the guidelines of this program and is available for ballistic testing. Included in this report is a general analysis of facility requirements to implement salt solutionizing heat treatment into the Aerojet production stream.

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INTRODUCTION

The objective of the program was to evaluate and demonstrate the viability of salt solutionizing heat treatment as an alternative heat treatment process to vacuum solutionizing. The slow cycle times of the existing process and the high frequency of maintenance required on the expensive capital equipment associated with vacuum solutionizing provided the incentive to Aerojet and the U.S. Army to identify an alternate solutionizing process. Salt solutionizing was investigated as a method for alleviating these problems. In spite of the fact that a vacuum outgassing operation must be performed prior to the salt solutionizing process itself, the quantities of blanks that would conceivably be outgassed during any one production-type cycle, greatly exceed those currently vacuum solutionized at one time. This is because the combination outgassing/solutionizing process is limited by the thermal efficiency of the quench operation which, in turn, seriously impacts quantities. Therefore, a large number of blanks could be outgassed at one time and then sent through the salt solutionizing process in smaller solutionizing lots without adversely affecting overall throughput. The smaller lots, in turn, also have the associated benefit of potentially providing a more uniform cooling condition and less distortion than the combination batch process.

SCOPE

This investigation was conducted in three phases consisting of a total of six development steps at the TNS facility in Jonesborough, Tennessee. Each of these steps, excluding the first two, used the information obtained in the preceding steps. The program logic diagram is shown in Figure 1.

The first phase, Phase A (Step 1), was the production of a control group using current M774 production practices. This material was used to compare vacuum solutionizing with salt solutionizing by analyzing the mechanical properties of the respectively heat treated material. The second phase, Phase B, consisting of Steps 2 through 6, developed the most economical and applicable salt solutionizing heat treatment process consistent with Aerojet's current mode of large caliber core production. The final phase, Phase C, of the program was the production of 40 finish machined and inspected M774 penetrator cores, the blanks of which were salt solutionized using the guidelines determined in Phase B. These cores are available for submittal to the Armament Research and Development Center (ARDC) for further evaluation and testing.

MATERIAL

A total of 141-33mm diameter by 384mm long U-.75 wt. % Ti core blanks were required for this study. The processing stages, reduction of UF_4 (green salt) through blanking, used to produce the core blanks for this program were those used in standard M774 operating practices and procedures. The core blanks were selected from remelt heats with three different titanium levels. Re-melt heat, billet identification, core blanks selected per billet, and billet titanium content are listed in Table 1. These three titanium levels were selected to identify any possible relationship between titanium level, process variations and mechanical properties.

All material was traceable per the applicable section of MIL-C-63308A. Complete traceability was maintained back to the green salt (UF_4) used. The core blanks were identified according to titanium level and remelt billet. The blanks from each billet were consecutively numbered with respect to extrusion order (first material out of extrusion die numbered one and so forth).

PROCESS DESCRIPTION

The government-furnished Sunbeam vacuum solutionizing furnace was used for the solutionizing of Control Group (Step 1) material. The core blanks for Phases B and C were vacuum outgassed at Battelle Columbus Laboratories. The Battelle furnace used was a top loading, 450mm diameter ABAR cold wall furnace. This piece of equipment was chosen to provide consistent outgassing conditions. The core blanks were placed horizontally in the furnace on a sheet of copper, supported by a stainless steel stand. At the completion of the outgassing cycle, the blanks were allowed to furnace cool to room temperature in an argon atmosphere.

The salt heat treatment was conducted in a NaCl-KCl neutral salt heated to 850°C in the 226 liter steel pot of a gas fired furnace. The melting point and working range of this salt was 665°C and 700°-890°C, respectively. The blanks were hung in copper-coated, Inconel baskets from a stainless steel rack. The rack had the capability of supporting eight baskets with 160 millimeters between core blank centers. The rack and basket fixture is shown in Figure 2. The core blanks were quenched into a 340 liter, unagitated tank of ambient temperature water. The immersion rate was controlled by a mechanically driven vertical shaft. The immersion rate was set at 46 cm/min. for all quenching cycles. The salt solutionizing equipment set-up used by Aerojet for this program is shown in Figure 3.

All aging was conducted in the Upton lead pot currently used in AOC large caliber core production. The aging heat treatment was performed at 370°C for 6 hours.

RESULTS

The salt solutionizing study sample schedule is shown in Table 2. The core blanks utilized by Aerojet in each step are listed in Table 3.

The Control Group blanks, Step 1, were solutionized in the government-furnished Sunbeam furnace. The results of hydrogen and mechanical property analyses and tests are listed in Table 4. It was confirmed by this data that the material selected for this program would meet M774 mechanical property specifications when processed according to the applicable production procedures.

The second phase, Phase B, of this program was the development of a salt solutionizing process. This investigation was divided into five steps. The first developmental step, Step 2, was to determine the outgassing characteristics and requirements of the material selected for this program. The hydrogen analysis results of this investigation are listed in Table 5. It was determined in Step 2 that outgassing the core blanks at 850°C for two or four hours would result in material with acceptable hydrogen levels, (<1.0ppm H_2), with the four hour outgas producing the lowest hydrogen levels. At this stage of the program, it was felt that 600°C for four hours was a marginal time-temperature outgassing combination (H_2 levels near the 1.0 ppm limit) and this outgassing condition was eliminated from further consideration.

Utilizing the four hour outgas at 850°C, 36 core blanks were outgassed for Step 3, Salt Solutionizing - 1st Iteration. The outgassed blanks were heated in the salt, six blanks at a time, for the specified times. The transfer times between removing the blanks from the salt and the initiation of the immersion cycle were changed from 10 and 20 seconds to 15 and 25 seconds respectively. The rationale for this change from that originally proposed was simply the fact that the fastest transfer time which could be safely obtained was 15 seconds. An originally intended increment of 10 seconds was maintained and the second transfer time was set at 25 seconds.

The results for Step 3 are listed in Table 6. Comparing the charpy test and microstructure results, it appeared that a salt residence time of 10 minutes was marginal and that 20 minutes would be sufficient. To determine the required residence time, a core blank was thermocoupled as shown in Figure 4. The thermocoupled blank was then lowered into the 850°C molten salt bath to determine the material heat-up rate and thus, the required salt residence time. The signal from the thermocouple was recorded on a strip chart and the resulting information is shown in Figure 5. As can be seen, the center of the core blank approached the bath temperature in five to eight minutes, but several additional minutes were required for the salt bath temperature to recover to the set point. As 10 minute increments had been proposed for the program, 20 minutes was chosen as the best salt residence time. It was determined that by the use of a larger bath or by an increase in the furnace heating capability, a shorter salt residence time could conceivably be used to increase throughput. The Step 3 data also indicates that there is no detectable amount of hydrogen pickup by the DU from the exposure to NaCl-KCl salt. This eliminated hydrogen pickup as a consideration in determining the salt residence time, within the range of time required to uniformly heat core blanks, in this salt.

In Step 4, the second best outgassing process was combined with the two most applicable salt residence-transfer time solutionizing processes. Table 7 shows the process used and the resulting data. It can be seen from the data that these processing combinations produced material with acceptable properties. Comparing the results from the two transfer times used, there appears to be no identifiable effect from the additional delay. The material cooling rate was analyzed by attaching thermocouples to the surface and sub-surface of a core blank which was salt solutionized. The results of this investigation are shown in Figure 6. As can be seen, the blank temperature at the surface does air-cool to below the transformation temperature of 745°C in approximately 60 seconds. Microstructural examinations did not identify substantial amounts of undesirable microstructure, but it is recommended that a short transfer time be used or some type of insulating fixture be employed to reduce the cooling of the material. Minimizing transfer time is especially important as the tail ends of the blanks are exposed to the air for a longer period of time than are the nose areas, prior to immerision into the quench media.

Also investigated under this step of the program was the distortion of the core blank resulting from the quenching stage of the salt solutionizing heat treatment. Table 8 shows total indicated runout (TIR) data of Step 4 material. This information can be compared to TIR data obtained from M774 blanks processed through the Sunbeam vacuum solutionizing furnace, also included in Table 8. It can be seen from this data that due to the configuration of the blanks in the quenching rack, the salt solutionized blanks were exposed to a more even cooling environment, thus resulting in less distortion from the solutionizing heat treatment.

Steps 5 and 6 were conducted as verification tests on low and high titanium levels. The resulting data from these tests are shown in Tables 9 and 10. The verification test data, as well as the control group data, does show that lower Ti contents did result in higher slow bend pre-cracked charpy (K_Q) and elongation (% E) values. All of the material for this program was aged for six hours at 370°C. It was not totally unexpected that lower Ti content material would exhibit somewhat higher fracture toughness and tensile ductility by virtue of titanium content alone. However, one would have also expected to see a correspondingly lower hardness associated with these results. This was not found. This correlation, or the lack thereof, has no specific significance for evaluation of the salt solutionizing process.

The final phase of this study was the production of 40 finish machined M774 penetrators. From the previous five development steps, it was concluded that the optimum process for this pilot operation was a two hour outgassing cycle at 850°C combined with a 20 minute salt residence time and a 15 second transfer delay. Forty three core blanks were selected from the nominal titanium level remelt heat (#3357) and heat treated according to this optimum process. Once solutionized, the core blanks were all aged together for six hours at 370°C. The aged blanks were then O.D. turned and submitted for ultrasonic and O.D. hardness evaluations. Two blanks, NA10 and NA14, were selected as representative blanks and submitted for mechanical property evaluations. As shown on the data sheet for this material, Table 11, O.D. hardness testing indicated that 10 of the 41 remaining blanks had O.D. hardness values greater than the Rc 44 specification limit. The collective hardness range and average values for these 10 were Rc 44.2 - 45.8 and Rc 44.7 respectively.

In the interests of completing this program, all of the 41 remaining pilot lot cores were machined. Of these, 40 dimensionally acceptable cores were produced, nine of which represented cores having the out-of-specification O.D. hardness.

CONCLUSIONS AND RECOMMENDATIONS

The salt solutionizing heat treat process established by this program for M774 core blanks was a two hour outgassing cycle at 850°C combined with a salt residence time of 20 minutes and a transfer delay time of 15 seconds. It should be noted that a recommendation for a 10 minute residence time can be made based upon a thermocoupled core blank test run. This recommended residence time is dependent on utilizing an appropriately sized salt bath with better temperature recovery capabilities than that used for conducting this study.

It was also determined that exposure to the NaCl-KCl neutral salt used in the solutionizing process did not affect the final hydrogen level measured in the D.U.-.75 wt. %Ti material. This program has demonstrated the technical viability of utilizing a salt solutionizing heat treatment in conjunction with Aerojet's processing of M774 large caliber cores. Some questions do arise about the possible utilization of this heat treatment technique for other cores (M833, XM829). This is based on the fact that these latter cores require higher ductility values than that specified for M774 penetrators. The ductility (% E) values obtained in this program, in some cases, are lower than the 16% elongation required for both M833 and XM829 cores. In addition, economic, safety and other factors must be fully identified and analyzed.

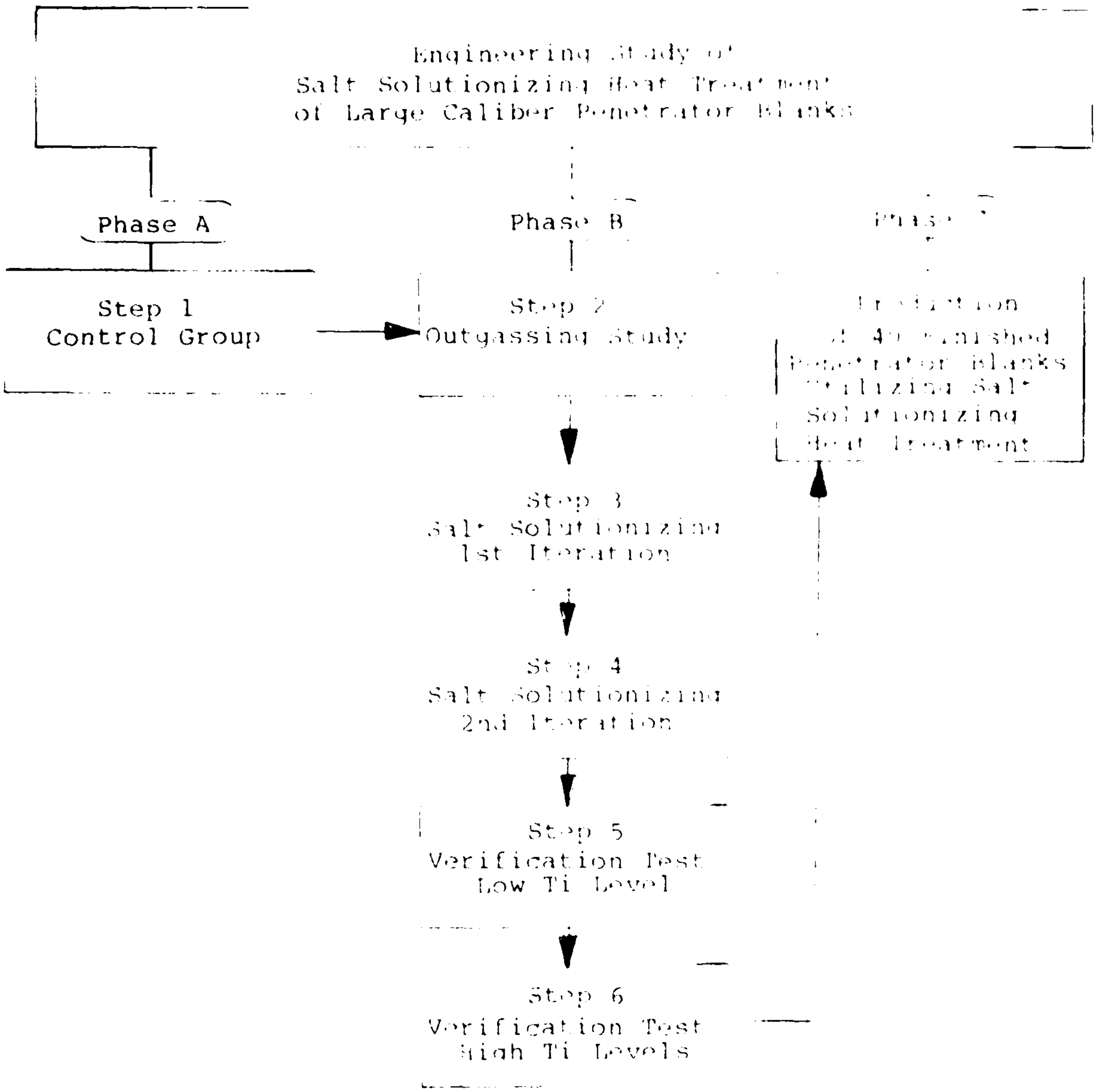

Figure 1. Logic diagram of salt solutionizing study process

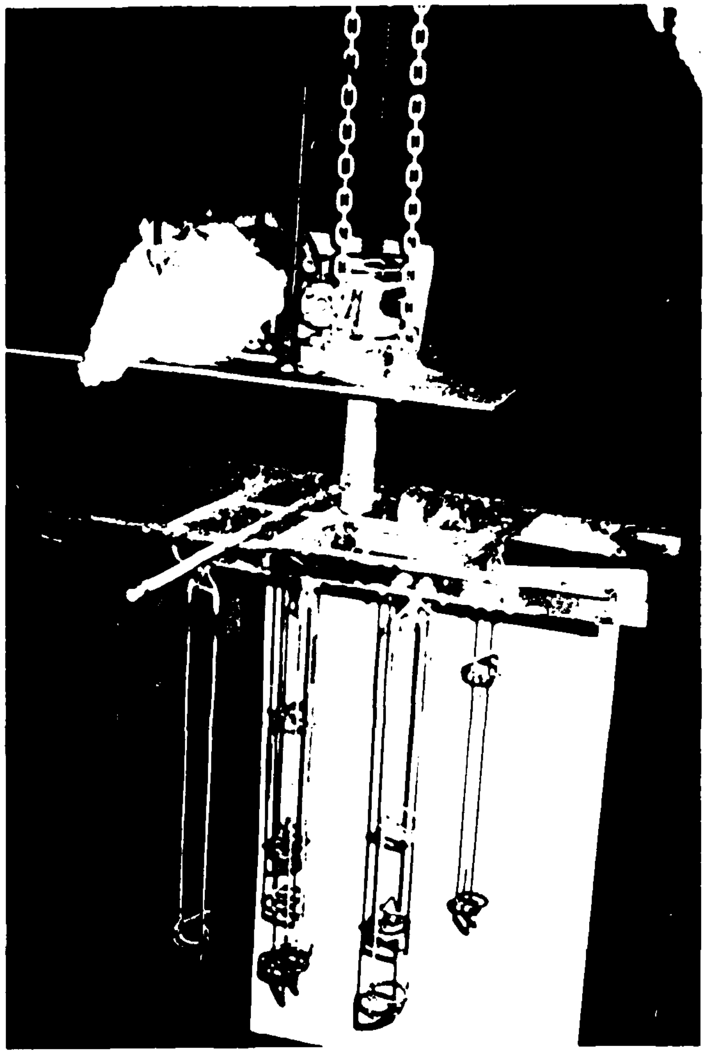

FIGURE 2: Photograph of solutionizing rack and basket fixture.

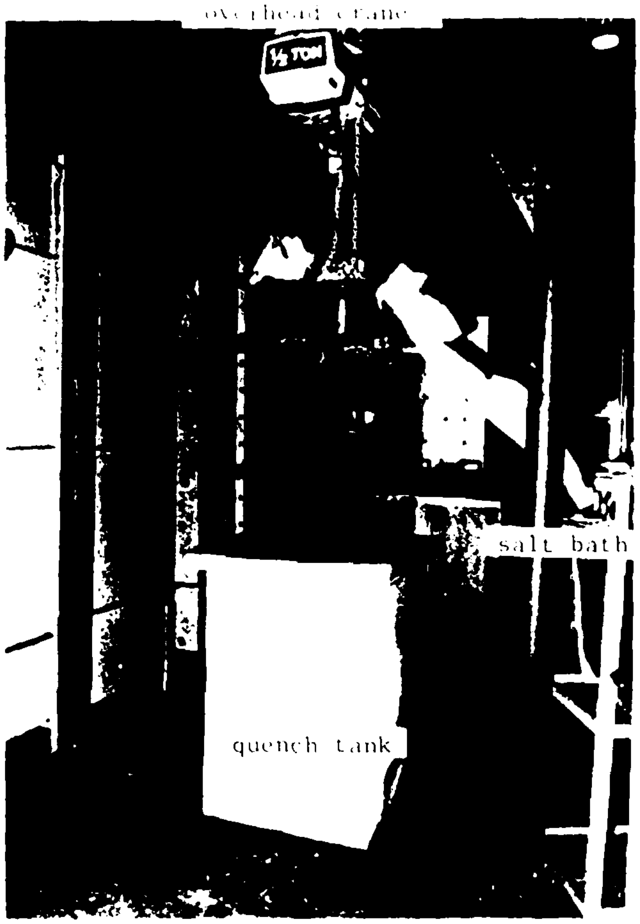

FIGURE 3

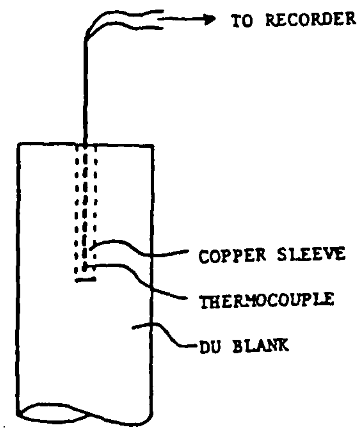

Figure 4. Diagram illustrating thermocoupled core blank

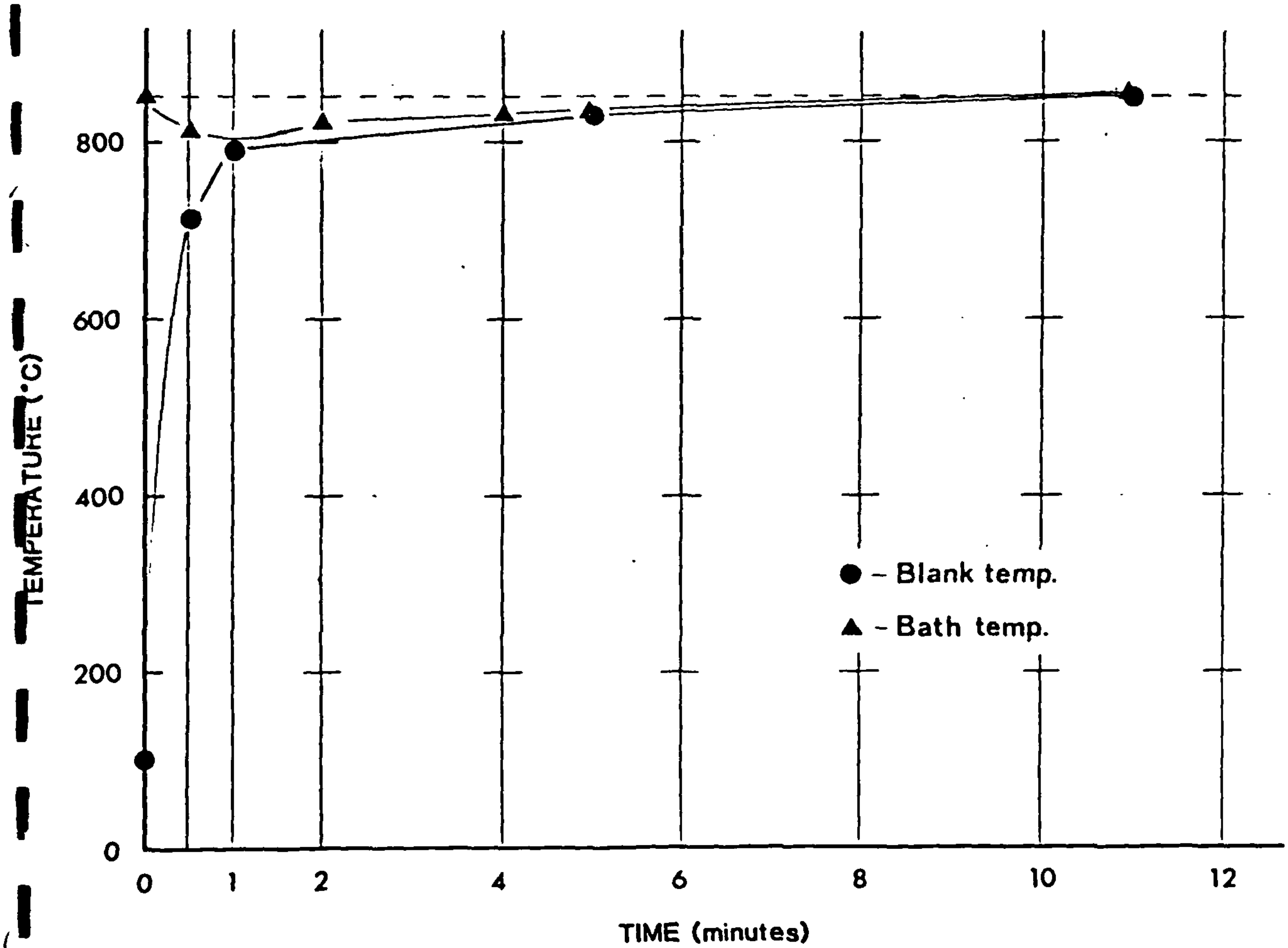

Figure 5. Heat up rate of an M774 core blank

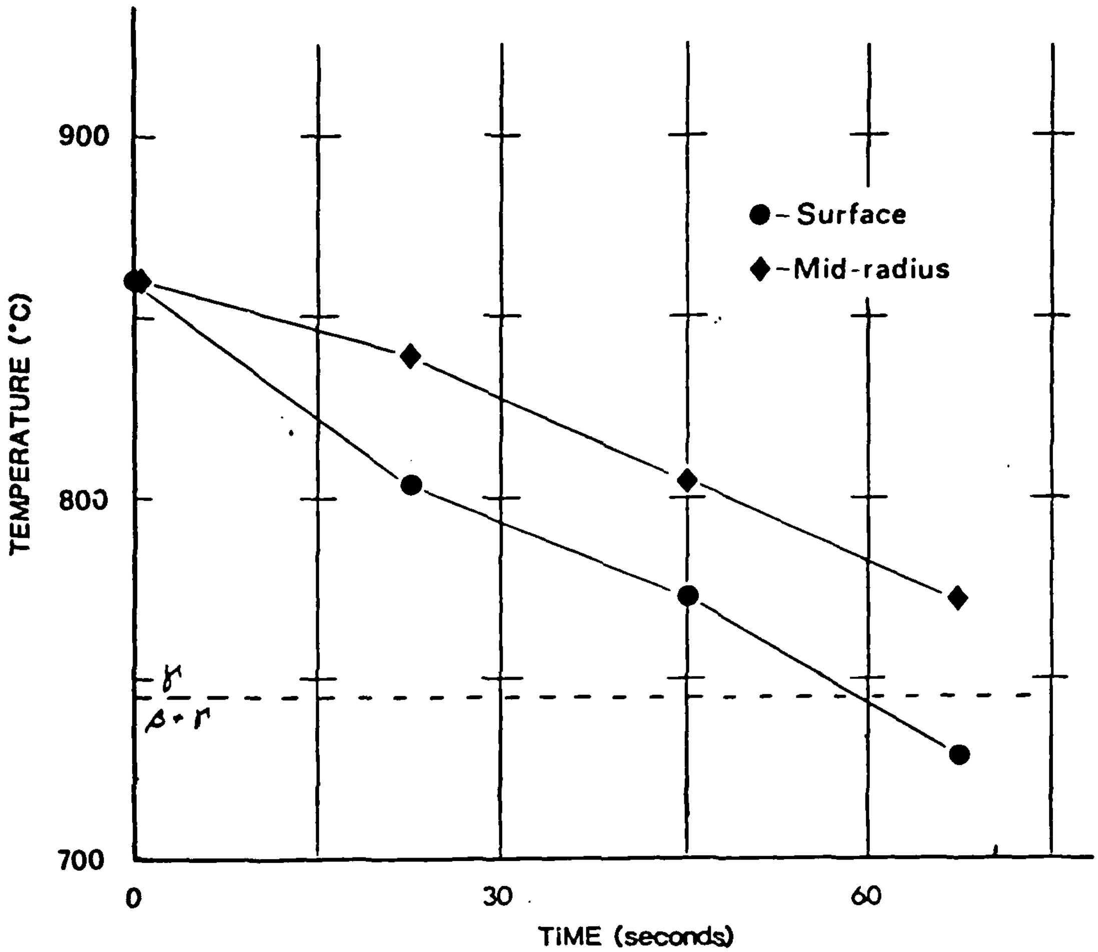

Figure 6. The cooling rate of a core blank when removed from the salt bath is plotted. Thermocouples were located at mid-radius and near surface of an M774 core blank.

Table 1. Program material selection

Remelt heat	Billet identification	Number of core blanks	Billet titanium range
3295	E	*14	Low (0.69-0.72% Ti)
3357	A,C,D,E,K	113	Nominal (0.73-0.75% Ti)
3303	E	*14	High (0.76-0.79% Ti)

*all blanks from same billet

Table 2. Salt solutionizing study sample schedule

	Titanium level code	Outgas condition code	Salt residence time (min.)	Transfer time (sec.)	Total cores processed	Cores H_2 tested before age	Cores H_2 charpy and tensile tested after age
	Step 1						
	L	R			6	2	4
Phase A	N	R			6	2	4
	H	R			6	2	4
	Step 2						
	N	1			6	6	
	N	2			6	6	
	N	3			6	6	
	Step 3						
	N	X1	10	15	6	2	4
	N	X1	10	25	6	2	4
	N	X1	20	15	6	2	4
	N	X1	20	25	6	2	4
Phase B	N	X1	30	15	5	2	4
	N	X1	30	25	5	2	4
	Step 4						
	N	X2	S-Q1		6	2	4
	N	X2	S-Q2		6	2	4
	Step 5						
	L	X-S-Q			8	4	4
	Step 6						
	H	X-S-Q			8	4	4
Phase C	Pilot lot						
	N	*X-S-Q			43		2
				Total	141		

Codes used:

<u>Titanium lots (wt. %)</u>
L = low (0.69-0.72% Ti)
N = nominal (0.73-0.75% Ti)
H - high (0.76-0.79% Ti)

<u>Vacuum outgas</u>
R = current solution procedure
1 = 600°C 4 hours
2 = 850°C 4 hours
3 = 850°C 2 hours
X1 = best outgas
X2 = second best outgas

<u>Other</u>
S-Q1 = best residence-transfer combination
S-Q2 = second best residence-transfer combination
X-S-Q = best overall heat treat combination
*X-S-Q = best overall heat treat combination for AOC large caliber core production

Table 3. Program core blank - process correlation

Core blank identification	Program step
EL1	1
EL6	1
EL7	1
EL8	1
EL9	1
EL10	1
EL11	5
EL12	5
EL13	5
EL14	5
EL15	5
EL16	5
EL17	5
EL18	5
EH1	1
EH6	1
EH7	1
EH8	1
EH9	1
EH10	1
EH11	6
EH12	6
EH13	6
EH14	6
EH15	6
EH16	6
EH17	6
EH18	6
NA1 through NA20	Pilot lot
NA21	1
NA22	1
NC1	2
NC2	2
NC3	2
NC4	2
NC5	2
NC6	2
NC7	2
NC8	2
NC9	2
NC12	3
NC13	3
NC14	3
NC16	3

Core blank identification	Program step
NC17	3
NC18	3
NC19	3
NC20	3
NC23	1
NC24	1
NC25	3
NC26	3
ND1	3
NC2	3
ND3	3
ND4	3
ND5	3
ND6	3
ND7	3
ND8	3
ND9	3
ND10	3
ND11	3
ND12	3
ND13	3
ND14	3
ND16	3
ND17	3
ND18	3
ND19	3
ND20	3
ND21	3
ND22	3
ND23	3
ND24	3
ND25	1
ND26	1
ND27	3
NE1	2
NE2	2
NE3	2
NE4	2
NE5	2
NE6	2
NE7	2
NE8	2
NE13	2
NE14	4
NE15	4
NE16	4
NE17	4
NE18	4
NE19	4
NE20	4
NE21	4

Core blank identification	Program step
NE22	4
NE23	4
NE24	4
NE25	4
NK1 through NK23	Pilot lot

Table 4. Control group (step 1) results

Core blank ident.	Titanium level	Hydrogen results (ppm)		Mechanical properties after age			
		Before age	After age	UTS (ksi)	Y.S. (ksi)	%E	K_Q (ksi$\sqrt{in}$)
EL1	Low	0.7					
EL6	(0.69-0.72 wt/o)	0.7					
EL7			0.7	203.1	108.9	20.1	39.5
EL8			2.9	201.1	109.4	21.4	37.5
EL9			0.7	199.2	107.8	14.9	38.6
EL10			0.7	199.7	107.1	19.0	35.1
NA22	Nominal	0.9					
NA23	(0.73-0.75 wt/o)	-					
NA21			1.6	208.4	119.4	12.6	30.7
NC24			0.3	206.7	114.6	15.6	34.2
ND25			0.3	206.9	113.8	15.2	30.1
ND26			0.7	Invalid tensile test			32.8
EH1	High	0.4					
EH6	(0.76-0.79 wt/o)	0.7					
EH7			0.7	210.7	120.1	14.0	30.2
EH8			0.4	213.9	119.3	16.1	29.4
EH9			0.9	212.2	112.3	16.0	34.9
EH10			0.7	213.7	118.3	15.0	33.9

Table 5. Outgassing study (step 2) results

Core blank ident.	Outgassing condition* (2 x 10-5 Torr)	Hydrogen results (ppm)	avg.
NC1	600°C (1100°F) 4 hrs.	1.0	
NC2		0.9	
NC3		0.8	0.87
NC4		0.6	
NC5		1.0	
NC6		0.9	
NE4	850°C (1560°F) 2 hrs.	0.4	
NE5		0.3	
NE6		0.3	0.32
NE7		0.2	
NE8		0.5	
NE13		0.2	
NC7	850°C (1560°F) 4 hrs.	0.1	
NC8		0.1	
NC9		0.2	0.15
NE1		0.1	
NE2		0.2	
NE3		0.2	

*vacuum outgassed at BCL, furnace cooled in argon atmosphere

Table 6. Salt solutionizing - 1st iteration (step 3) results

outgassed: 4 hrs. at 850°C (1560°F) $<10^{-5}$ Torr
solutionized: 850°C (1560°F) NaCl - KCl salt
immersion rate: 46 cm/min.
aged: 6 hrs at 370°C (700°F) lead pot

Core blank ident.	Salt residence time (min)	Transfer time (sec.)	Tensile UTS (ksi)	Tensile Y.S. (ksi)	Tensile % elong.	Charpy K_Q ksi$\sqrt{in.}$	Center line hydrogen (ppm)
ND10	10	15	-	-	-	-	<0.1[b]
ND11			212.4	114.6	24.2	23.7[a]	0.5
ND12			210.7	120.2	21.0	25.0[a]	0.3
ND13			211.3	126.0	18.8	20.7[a]	0.4
ND14			-	-	-	-	0.2[b]
ND16			215.0	123.8	22.6	22.9[a]	0.5
NC12	10	25	210.7	122.4	25.0	32.5	0.6
NC13			211.9	124.3	17.5	34.1	0.2
NC14			212.7	124.7	22.3	31.0	0.2
NC16			210.5	127.1	17.7	30.0	0.4
NC17			-	-	-	-	0.2[b]
NC19			-	-	-	-	0.2[b]
NC18	20	15	212.5	122.1	22.2	32.9	0.1
NC20			-	-	-	-	0.1[b]
NC25			-	-	-	-	0.2[b]
ND1			210.8	121.1	21.0	32.9	<0.1
ND2			211.7	120.2	23.1	33.4	0.1
ND3			210.8	127.0	16.9	32.2	<0.1
NC26	20	25	-	-	-	-	0.9[b]
ND17			208.3	122.7	15.7	30.1	0.1
ND18			208.8	120.1	15.4	34.2	0.3
ND18			-	-	-	-	0.9[b]
ND19			210.2	117.8	22.5	31.8	0.1
ND20			205.4	120.8	15.2	33.8	0.3
ND4	30	15	210.8	123.2	24.2	26.1	0.3
ND5			-	-	-	-	0.1[b]
ND6			-	-	-	-	0.1[b]
ND7			208.3	121.8	13.8	32.8	0.3
ND8			214.1	124.7	20.6	25.8[a]	0.2
ND9			211.5	125.3	17.8	31.2	0.7
ND21	30	25	213.0	122.8	20.6	31.9	0.3
ND22			211.7	119.5	24.2	32.8	0.5
ND23			209.8	121.4	23.8	33.7	0.2
ND24			206.9	116.5	14.3	32.5	0.4
ND24			-	-	-	-	0.5[b]
ND27			-	-	-	-	0.5[b]

[a]material had poor microstructure
[b]hydrogen sample obtained before aging the material

Table 7. Salt solutionizing - 2nd iteration (step 4) results

outgassed: 2 hrs. at 850°C (1560°F) <10^{-5} Torr
solutionized: 850°C (1560°F) NaCl - KCl salt
immersion rate: 46 cm/min.
aged: 6 hrs. at 370°C (700°F) lead pot

Core blank ident.	Salt residence time (min)	Transfer time (sec)	Tensile UTS (ksi)	Tensile Y.S. (ksi)	Tensile % elong.	Charpy K_Q ksi$\sqrt{in.}$	Center line hydrogen (ppm)
NE14	20	15	210.6	117.3	18.6	31.3	0.4
NE15	20	15	212.7	120.5	20.8	31.2	<0.1
NE16	20	15	-	-	-	-	0.4*
NE17	20	15	-	-	-	-	0.4*
NE18	20	15	213.9	121.0	17.7	32.6	0.2
NE19	20	15	209.5	120.1	17.3	31.9	0.2
NE20	20	25	208.2	119.6	20.5	35.2	0.2
NE21	20	25	211.2	119.0	15.4	33.2	0.3
NE22	20	25	-	-	-	-	0.1*
NE23	20	25	-	-	-	-	0.3*
NE24	20	25	213.7	124.1	17.4	33.8	0.2
NE25	20	25	206.0	126.1	14.0	29.8	0.3

*hydrogen sample obtained before aging the material

Table 8. Comparison of total indicator reading (TIR)* data of solutionized M774 core blanks

Vacuum solutionizing vs. salt solutionizing

	Vacuum (Sunbeam)	Salt
Sample size	95 core blanks (random sample)	12 core blanks (step 4 material)
Maximum TIR	0.82	0.16
Minimum TIR	0.03	0.03
Average TIR	0.27	0.11

Note: TIR was measured from tail end (numbered end). 2nd V-block was located 14 inches from the 1st V-block stop, where tail end of core blank is positioned.

*all units in inches

Table 9. Verification tests (step 5) results

outgassed: 4 hrs. at 850°C (1560°F) $<10^{-5}$ Torr
solutionized: 850°C (1560°F) NaCl - KCl salt
immersion rate: 46 cm/min.
aged: 6 hrs. at 370°C (700°F) lead pot

Core blank ident.	Salt residence time (min.)	Transfer time (sec.)	Tensile UTS (ksi)	Tensile Y.S. (ksi)	Tensile % elong.	Charpy K_Q, ksi$\sqrt{in}$	Center line hydrogen (ppm)
EL11	20	15	202.8	109.1	22.9	38.5	0.1
EL12	20	15	200.7	109.4	22.5	36.2	0.1
EL13	20	15	200.6	108.9	21.4	36.8	0.2
EL14	20	15	202.3	108.6	22.3	37.4	0.1
EL15	20	15	-	-	-	-	0.1[a]
EL16	20	15	-	-	-	-	0.1[a]
EL17	20	15	-	-	-	-	0.1[b]
EL18	20	15	-	-	-	-	0.2[b]

[a]as-outgassed condition
[b]as-solutionized condition

Table 10. Verification tests (step 6) results

outgassed: 4 hrs. at 850°C (1560°F) $<10^{-5}$ Torr
solutionized: 850°C (1560°F) NaCl - KCl salt
immersion rate: 46 cm/min.
aged: 6 hrs. at 370°C (700°F) lead pot

Core blank ident.	Salt residence time (min.)	Transfer time (sec.)	Tensile UTS (ksi)	Tensile Y.S. (ksi)	Tensile % elong.	Charpy K_Q ksi$\sqrt{in.}$	Center line hydrogen (ppm)
EH11	20	15	213.6	128.1	18.2	31.6	0.2
EH12	20	15	211.5	124.2	16.8	31.1	0.1
EH13	20	15	214.2	122.4	20.1	32.7	0.2
EH14	20	15	213.1	121.3	14.4	31.6	0.1
EH15	20	15	-	-	-	-	0.2[a]
EH16	20	15	-	-	-	-	0.2[a]
EH17	20	15	-	-	-	-	0.1[b]
EH18	20	15	-	-	-	-	0.2[b]

[a]as-outgassed condition
[b]as-solutionized condition

Table 11. Pilot lot cores

outgassed:	2 hrs. at 850°C (1560°F) <10^{-5}
solutionized:	850°C (1560°F) NaCl - KCl salt for 20 minutes
transfer time:	15 seconds
immersion rate:	46 cm/min.
aged:	6 hrs. at 370°C (700°F) lead pot

Pilot lot blank no.	Core blank identification	Comment	Hardness (R_C)
1	NA1		
2	NA2		
3	NA3	High O.D. HR_C	44.2
4	NA4	High O.D. HR_C	44.5
5	NA5		
6	NA6		
7	NA7	High O.D. HR_C	44.5
8	NA8	High O.D. HR_C	45.8
9	NA9		
10	NA10		
11	NA11		
12	NA13	High O.D. HR_C	45.5
13	NA15	High O.D. HR_C	44.5
14	NA16	High O.D. HR_C	44.3
15	NA18	High O.D. HR_C	44.4
16	NA19		
17	NA20		
18	NK1	High O.D. HR_C	44.8
19	NK2		
20	NK3		
21	NK4		
22	NK5		
23	NK6		
24	NK7		
25	NK8		
26	NK9		
27	NK10		
28	NK11		
29	NK12		
30	NK13		
31	NK14		
32	NK15		
33	NK16		
34	NK17		
35	NK18		
36	NK19		
37	NK20		
38	NK21		
39	NK22		
40	NK23		

Pilot lot blank number	Core blank identification	Comment	Hardness (R_c)
	NA17	Machining reject and high O.D. HR_c 44.3	

Mechanical property samples

	Tensile			Charpy	Center line
	UTS (ksi)	Y.S. (ksi)	% elong.	K_Q ksi$\sqrt{in.}$	hydrogen (ppm)
NA10	218.1	131.1	19.2	31.1	0.3
NA14	216.3	127.3	20.3	30.7	0.7

FACILITIZATION FOR SALT SOLUTIONIZING HEAT TREATMENT

To incorporate salt solutionizing into the process stream of large caliber core heat treatment, several capital items would be required. Essentially, this new stage of heat treatment would replace the heat treatment now conducted by the AVS and Sunbeam solutionizing furnaces. If salt solutionizing is implemented into the production stream, the AVS and Sunbeam could be utilized as outgassing furnaces to support this process. Whether or not these pieces of equipment would be converted is not known and subsequently not considered in this evaluation. The process and equipment specified is done so with the considerations that the input to this new process would be as-blanked core blanks. The output of this designed process would be solutionized core blanks, free of salt, ready for the aging or straightening process. Thus, the salt solutionizing process would require a new outgassing furnace, salt bath, quench tank and wash station.

The potential labor savings from the salt solutionizing process are estimated at approximately .057 hr./core. Associated dollar values are not presented here because of the sensitivity of that information. In addition, the dollar value is only applicable to a specific manufacturing operation and would be misleading if applied to another manufacturer.

The production rates used as design criteria are consistent with the FY '83 mobilization option quantities of 10,000 M833 and 4,000 XM829 cores per month each. These rates are achieved utilizing 70% of maximum equipment capability per 500 hours on a 3/8/5 shift basis. At these rates and shift basis, the actual heat treating requirements for M833 and XM829 core blanks would be 13,000 and 5,200 cores per month, respectively.

Outlined on the following pages are the required equipment and general specifications. The specifications are those as determined by this study. Included with these specifications are equipment sources and cost figures obtained from quotations received in forth quarter 1983.

Salt Solutionizing Process Equipment

Outgassing Furnace

Equipment Specification

Capacity:	17600 Kg (8000 lbs.)
Vacuum Level:	[10-4 Torr
Soak Temp:	850 C (1560 F)
Soak Time:	2 hrs.
Total Cycle Time (load-unload):	5.5 hrs.

Source: AVS

Base system, diffusion pumping system, cool down heat exchanger system	$242K
Outgassing baskets 2 baskets/furnace	11K
Installation	40K
	$293K

Salt Solutionizing Process

Process Specifications

Capacity:	80 blanks per hour (20 blanks per load)
Bath Temp:	850 C
Salt Residence Time:	10 minutes
Immersion Rate:	40-60 cm per minute
Cycle Time:	15 minutes

Source: Upton

Complete system including fixtures, quench tank, hoist superstructure, canopy, platforms, and installation	$280K
	$280K
Water Spray Area for Salt Removal	$ 10K
Total	$583K

Production Area

Erection of a 700 sq. meter (7500 sq. ft.) facility including electric, plumbing and ventilation service	$375K
Total Cost	$958K

TABLE 12

SALT SOLUTIONIZING

CHEMICAL ANALYSIS

OF

HEATS TESTED

ELEMENTS	HEAT 3357	HEAT 3303	HEAT 3295
Al	< 15	< 15	< 15
Ba	< 5	< 5	< 5
Co	< 0.6	< 0.6	< 0.6
Cr	< 5	< 5	< 5
Cu	8	8	5
Fe	20	20	20
Mg	< 4	< 4	< 4
Mn	6	7	7
Ni	6	5	8
Si	49	29	65
Ti	.74	.78	.71
V	< 5	< 5	< 5
Zn	< 10	< 10	< 10
C	45	23	44

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